Yasser Arafat's headquarters. Furthermore, by starting construction on a new settlement in East Jerusalem, Israel stirred new anger among the Palestinians. However, there is a slight glimmer of hope. The Israeli army has so far refrained from entering the Gaza strip to search for terrorists, and the USA and the EU have started a new all-out effort to bring both sides back to the negotiating table. A lasting peaceful solution would eventually make an academic boycott unnecessary—something that Jablonka actually would like to see. 'I hope that there is no need for a boycott,' Jablonka said. 'I don't want this to happen.'

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Biotechnology: the next engine of growth for Taiwan's economy?

The Taiwanese government is investing heavily in biotech infrastructure and researchers in an effort to repeat the country's success with IT technologies

On a recent visit to the Genome Research Center (GRC) at Taiwan's National Yang-Ming University in Taipei, its director, Kwang-Jen Hsiao, pointed to a brightly highlighted line in a list of contributors to the Human Genome Project (HGP). 'If we [were one of the official HGP consortium members],' he said, 'that is where we should be.' The list—reproduced and altered to include the GRC—was from a page in the historic February 2001 issue of the journal *Nature*. GRC's contribution, 12 megabases of work mostly on Chromosome 4, was about two-thirds down the page.

Taiwan's role in the HGP—hidden but significant—is reflective of the country's position in the world-wide biotechnology community. But the assumption that it is only a minor player belies the fervour of recent efforts to build a research infrastructure and to develop its biotechnology sector. Indeed, biotechnology has moved into Taiwan's science parks and onto the national agenda. It has gained the commitment of the government, and expectations are high that this will become the next engine of Taiwanese economic growth. In 1997, the value of new biotechnology industries in Taiwan was estimated at $14.7 billion Taiwan dollars (€440 million) and the Ministry of Economic Affairs predicts that it will grow to NT$80 billion (€2.5 billion) by 2005.

With growing interest from the government, businesses and venture capital firms, hopes are high in Taiwan that the factors which led to the island's strength in semiconductor manufacture and IT-related industries will also translate to biotechnology. But there are many differences between the two industries and the learning curve may prove to be steep. In addition, not only must Taiwan play 'catch-up' within a fairly narrow window of time and against strong international competition, but the island's size and limited experience—23 million people and a high-tech history that spans only a few decades—mean it requires some creative approaches to carve out its own niche.

> Biotechnology has moved into Taiwan's science parks and onto the national agenda

Part of that solution may lie in its emphasis on collaboration. This actually is a sensible approach for such a small country. Taiwan's population is roughly one-fifth of its neighbour Japan and one-tenth of the USA. Through grant schemes to promote scientific excellence, the government has identified and promoted research targets to build up an academic infrastructure and subsequently plans to interlink these centres to provide resources for the greater Taiwanese research community. While university budgets are shrinking, notes Ueng-Cheng Yang, Director of Yang-Ming University's Bioinformatics Program, this support has been a real boost.

One target for this approach is education in bioinformatics. The first course offered in 1990 was simply called 'Computer Applications in Life Science', and government support over the intervening decade has allowed universities not only to educate young researchers, but to train instructors as well. The first masters-level programme in bioinformatics was established at National Yang-Ming University in 2000, made possible by one of seven grants (chosen from more than 200 applications) under the programme to promote scientific excellence. Starting in 1997, the Ministry of Education sponsored summer courses at national universities for researchers from industry, other universities and even high school teachers, under the Biotechnology Education Improvement Program. The National Science Council went on to help establish undergraduate programmes, which began at several universities in January 2002. In 2000 and 2001, NSC funded about 50 projects through a special short-term grant programme, which provides incentives, in the form of more money and a higher acceptance rate, to encourage bioinformatics. Governmental support also enabled the establishment of Yang-Ming University's Bioinformatics Research Center in 2001. With 53 computers and a total of 77 Gbytes of RAM, it is, according to Yang, the largest biocomputing resource in Taiwan.

Some basic facts about Taiwan

Population: 22 370 400 (July 2001, estimated)
Land area: 32 260 km^2
Government: multiparty constitutional democracy, headed by popularly elected president Shui-bian Chen
Gross domestic product: US$386 billion (2000, estimated), growth rate 6.3%
R&D investment in 1999: 2.05% of GDP
Economy: agriculture 3%; industry 33%; services 64%
Exports: US$112.6 billion; Imports: US$98.7 billion (2001)

Taiwan has a capitalist economy with gradually decreasing guidance by the government. GDP growth has averaged about 8% during the past three decades. Exports have grown even faster and have provided the primary impetus for industrialisation. Inflation and unemployment are low; the trade surplus is substantial, and the country has the world's fourth largest foreign reserves. Traditional labour-intensive industries are steadily being moved offshore and replaced with more capital- and technology-intensive ones. Taiwan has become a major investor in China, Thailand, Indonesia, the Philippines, Malaysia and Vietnam. Because of its conservative financial approach and its entrepreneurial strengths, Taiwan suffered little compared with many of its neighbours from the Asian financial crisis in 1998–1999.
Data are based on the CIA World Factbook (http://www.cia.gov/cia/publications/factbook/index.html)

Towards the end of 2002, the first graduate institute will open at National Chao-Tung University. In addition, four national universities are joining with the National Health Research Institute (NHRI) and the National Center for High Performance Computing (NCHC) to form the Taiwan Bioinformatics Institute. Through internship programmes and links with the NCHC and NHRI, students are getting direct hands-on experience in the actual research projects of Taiwan's biotechnology community. The first students are just graduating from Yang-Ming (six in the first year, 12 in the next) and demand is so high that they are immediately being courted by industry. The need for qualified people, Yang said, has made it hard to develop a steady core of instructors.

Another example of the collaborative approach is the new National Research Program for Genomic Medicine. This year, the government identified 10 core research centres at academic institutions across the island, which it will fund to the tune of US$30 million. The concept works like this: in exchange for government funding, core laboratories serve as national technology platforms by educating and providing services for researchers around the island. Typically, the government provides funding for equipment, the university contributes personnel, and collaborative researchers pay for the centre's services and supply their own consumables. Core centres may also run workshops for researchers in Taiwan, to introduce platform technologies and provide a forum for information exchange.

In fact, three of these national core laboratories—involved in expression analysis, bioinformatics and sequencing—are located at Yang-Ming University and they are rapidly expanding. For instance, researchers at Hsiao's Genome Research Center plan to add eight new sequencers, which is made possible by government funding of some US$8 million per year from 2002 to 2005. 'We are going to triple our operation with this new funding,' notes Peter Tsai, Director of the division of molecular and genomic medicine at the NHRI and a Professor at Yang-Ming.

> The importance of the overseas Chinese community for Taiwan's biotechnology sector cannot be overestimated

Greater capacity will also increase Taiwan's contribution to international sequencing efforts. Through the Academia Sinica's Botany Institute, Taiwan is already a member of the International Rice Genome Sequencing Project. The Yang-Ming GRC has also joined the international consortium led by Japan, which plans to sequence the bulk of the chimpanzee genome within the next 3 years. A user's committee will determine where to devote the centre's sequencing capacity as part of the national genomic medicine programme. 'Helping other researchers to utilise genome technology to do biomedical research,' said Hsiao, 'that's the whole concept.' In addition, the Taiwanese centres collaborate with other sequencing centres from abroad—GRC and the Sanger Centre recently published their sequence of *Streptomyces coelicolor* in *Nature*. Other genomes being worked on in Taiwan include various bacteria, plant and human pathogens, mosquitoes and the Ling-chi mushroom, the latter being more important for domestic research. 'Of course we have our own interests,' said Tsai. 'But I think it's important to help people to take advantage of this technology, either on the Yang-Ming campus or throughout Taiwan.' It is by virtue of its previous internal collaborations, including work on the human genome, says Yang, that Yang-Ming became a model for the national programme.

In another initiative, the Ministry of Economics is supporting a pilot project to bring together biotechnology companies and academia. 'The government is using this as a test case, to see how they can [use] those research development grants to involve academic institutes,' Hsiao commented. This is a remarkable change in strategy from the previous model that focused support on industry, and that was criticised by academics, who claimed that their priorities had been pushed to the side. Academic researchers also want to keep control over the intellectual rights when an idea originates from a university laboratory, in contrast to projects sprung from corporate laboratories that may be developed through subcontracting to an academic institution. By supporting the academic researchers more, the government hopes for the establishment of new biotechnology companies. 'I think before,

this kind of initiative came from the company,' Tsai commented. 'Now the ideas come from the university.'

In its effort to carve out a niche, Taiwan is also emphasising a local approach, for example by pairing biotechnology with traditional Chinese medicine or by giving biomedical research priority to regionally significant diseases. For instance, the Ling-chi mushroom has long been regarded as a natural immune system booster, and research at Taipei Veterans General Hospital lends experimental evidence to this belief. When biochemical analysis proved difficult, researchers adopted a sequencing approach and finished a draft sequence in 2001. The Development Council for Biotechnology, which promotes links between academia and industry and between researchers overseas and in Taiwan, also has a special category for promoting research into traditional therapies.

One problem remaining for Taiwan is the increasing need for trained personnel, and the importance of the overseas Chinese community for Taiwan's biotechnology sector cannot be overestimated. Educated Chinese living abroad link the country's researchers with colleagues in the USA and mainland China. This community has provided an important network for information exchange, research collaboration and business opportunities in Taiwan. Perhaps the most prominent example is Yuan-Tseh Lee, who won the Nobel Prize for Chemistry in 1986 while in the USA, and who returned to head Academia Sinica, Taiwan's leading institution for basic research. Since his return in 1994, he has become the most influential figure in the advancement of Taiwan's biotechnological aspirations. Lee found two things in the USA that he wanted to bring back to Taiwan: biotechnology and venture capital. He is also the architect of the National Research Program for Genomic Medicine, and at Academia Sinica, Lee has established a biotechnology promotion committee, helped to set up a technology transfer office, and is promoting plans for a new Functional Genomics Center.

The know-how that built electronics will not necessarily translate into competence in biotechnology

Such networks were also essential for Taiwan's success in the electronics industry. But it is still unclear how much crossover the two fields will allow. 'Taiwan already has in place the advanced technologies in IC [semiconductor manufacture] and IT to drive the integration of these key technologies with basic knowledge on biological systems and biotechnology, such as fields of biocomputing and bioinformatics. The idea is to augment the existing IC and IT industry with a robust biotech industry to sustain the Taiwan economy at a healthy rate of growth,' writes Ying-Ta Wu, Special Assistant to Academia Sinica's Vice President Sunney I. Chan, head of the genomics programme. 'The integration could be accelerated,' he added, 'by the infusion of foreign know-how and foreign investments to promote cooperation.'

One area in which Taiwan's IT success is set to contribute directly to the growth of biotechnology is in financial support. Private investors not only have the liquidity to fund bioventure efforts, they are also eager to repeat their IT success. Wu estimates that in 2001, private individuals invested US$1 billion into bio-related businesses in Taiwan. Estimates of combined private–public investment in the coming years range from US$5 billion to US$10 billion.

But the know-how that built electronics will not necessarily translate into competence in biotechnology. Those in the community report a need for qualified people whose expertise covers law, business and science. And while universities are increasingly developing technologies through on-campus licensing offices, some researchers are simply not interested in pursuing that route, or do not know the intricacies of the system.

In some cases, the government has had to reconsider its approach. The Development Center for Biotechnology, established in 1984 when Taiwan first started to make its biotechnology push, was almost universally discredited for failing to build homegrown business. It has been reconstituted since 2000, with a new director and a new mission aimed at aiding technology transfer between business and academia within Taiwan and from overseas.

As Taiwan looks to improve its infrastructure for both research and business, there remain, in Wu's words, 'some key breakthroughs' to be made before Taiwan can compete with the rest of the world.' He suggested that principal investigators need to be able to take short leave from academia to work in private industry. And he placed a priority on incentives to attract experts from abroad to contribute to the biotechnology sector in Taiwan. Qualified personnel is also a critical issue—not only for industry but academia as well. Nevertheless, with such serious commitment from the government, internationally significant research and the network it feeds, and a number of interested investors, biotechnology in Taiwan seems to be gaining momentum.

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